# Analyzing Interface Bonding Schemes for VLC with Mobility and Shadowing


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***Abstract*—Node mobility and shadowing are the most common reasons requiring a handover in vehicular visible light communications (VVLC). In order to provide seamless mobility during the handover, it is required to decrease the network outage duration. This paper aims to improve the outage duration in handover caused by mobility and shadow for VLC networks. We analyze interface bonding schemes using two different primary interface reselection methods. The results show that using "failure" interface selection method instead of "always" method reduces the VLC handover outage duration by 62% and 44% in bonding schemes for transmission control protocol (TCP) and user datagram protocol (UDP) network traffic, respectively.**



***Index Terms*—Vehicular visible light communication, VLC Channel selection, link aggregation, frequency division, outage duration, handover**


## I. Introduction

Visible light communications (VLC) is seen as an alternative and complementary wireless technology to the radio frequency in a number of applications including vehicular communications. VLC systems operating in the visible band (375 and 780 nm) do not introduce any interference to radio frequency (RF) cellular networks and are free from RF induced interference [1]. In addition, it offers a large bandwidth, which implies good spatial resolution, high security, energy efficiency and low cost. However, there are several challenges facing VLC such as link blockage due to obstacles, shadowing, mobility and spatial diversity. However, in VVLC both mobility and shadows are the most challenging issues during handover in both vehicle to infrastructure (V2I) and vehicle to vehicle (V2V) communications. For automated guided vehicles (AGV) moving around a compound will experience frequent handover due to obstacles and shadowing, thus experiencing increased level of network outage. In order to have a low network outage and a highly reliable network, we propose a flexible VLC network architecture of Flight, which was introduced in [2]. The concept is based on the idea of using link aggregation on top of multiple VLC clients for an AGV and frequency division for neighboring VLC access points and their corresponding VLC clients. In this paper, we evaluate two different interface selection methods for the two main handover scenarios caused by mobility and shadowing, outline in detail their operation and presenting new sets of results.

The outline of the paper is as follows. Section II briefly discusses the related work in this domain. Section III presents the brief explanation of the Flight network architecture in VLC systems. Section IV presents the problem statement and section V explains the channel selection methods descriptions.Section VI demonstrates the experimental results and finally, section VII concludes the paper.

## II. Related work

There is a number of research works, focused on handover in RF- and VLC- based vehicular networks. In [3], a handover management approach is based on the received signal intensity for both overlapping and non-overlapping optical network scenarios. In this scheme, the handover is initiated prior to disconnecting the link followed by and then a new neighboring cell is found before leaving the current serving light cell. A handover procedure proposed in [4] is based on a pre-handover scheme, which relies on the position estimation obtained by visible light positioning and motion tracking with Kalman filters. In addition, a power and frequency-based soft handover method is proposed in [5], which reduces the data rate fluctuations as the mobile device moved between cells within the network. The proposal in [6] presents a statistical distribution of the received data rate using simulation tools. The handover proposed aims to extend the transmission bandwidth of VLC by minimizing the multipath induced channel dispersion. The algorithm deactivates those cells that did not cover the mobile user to decrease the overall root mean square delay spread. In [7], an implementation of a hybrid communication system, which supports the vertical handover between VLC and RF, is reported, which is a decision making scheme between network and data link layers. In this scheme, the primary VLC link is monitored and if the link is not no longer accessible switching to the RF link is initiated.

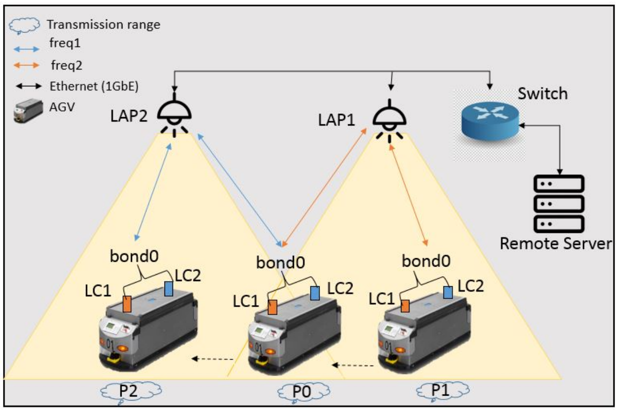



Fig. 1: Flight Architecture

In [8], a novel architecture is proposed to provide both high network performance and a seamless mobility in the RF domain. The proposed algorithm is called BIGAP, which is based on different channels assignment to the co-located access points (Aps) with the aim of full utilization of the available RF spectrum. BIGAP dynamically selects the operating frequencies, which is compatible with 802.11, and forces the client to change AP. BIGAP improves the outage duration during handover significantly, thus offering frequent and seamless handover and supporting both seamless mobility and efficient load balancing in the network. This is similar to Flight as both use different channel frequencies. In contrast to BIGAP, where only a single network interface for a client is needed, Flight approach requires multiple interfaces.

This paper makes use of commercial off-the-shelf (COTS) devices working with VLC where the neighboring light access points (LAPs) are operating on different channels and there is dedicated network interfaces for each VLC frequency. Moreover, we use the proposed Flight network architecture to improve network outage duration during handovers due to mobility and shadowing in a VVLC network environment.

## III. FLIGHT NETWORK ARCHITECTURE

Within a dense deployment of indoor LAPs in VVLC, Flight proposes a low network outage handover using dedicated optical transceiver modules (OSRAM) for both LAPs and light clients (LC). Flight ensures seamless VLC coverage within an indoor environment by establishing dense VLC network architecture. In this work, two methods of frequency division multiple access (FDMA) and Linux network bonding feature are adopted. Fig. 1 presents a general overview of a VVLC with links between the mobile device and the server under devices mobility and handovers between LAPs. AGVs moving directly on a straight path towards the LAPs establish VLC link connection using their VLC transceivers. As shown in Fig. 1, LAPs are connected to a remote server via a switch and the VLC link supports both uplink and downlink from an AGV to the remote server. Note, the overlap of coverage areas of LAPs to ensure seamless VLC network coverage. Each AGV is equipped at least with one LC, which is directed towards the ceiling for line-of-sight path to the LAP. As shown in Fig. 1, Flight utilizes FDMA and network bonding in the VVLC network. An AGV moves from LAP1 coverage area P1 to LAP2 coverage area P2 passing through the mutual area P0 between LAPs, network handover is initiated. Here, we have configured four LAPs and LCs to operate on two separate frequency bands, thus having two parallel VLC links. The frequency ranges for LCs are 4-52 MHz and 52-96 MHz, see Fig. 2. Both LAP and LC units are configured to operate in the same network subnet. In addition to FDMA, Flight uses the network bonding method, which is known as link aggregation that creates a bond logical configuration on top of two physical Ethernet interfaces of the Linux system. Among different network bonding modes, Flight uses the active-backup mode in order to meet the requirements for load balancing and linear scaling of the bandwidth, thus improving the link reliability. Within this mode, at any given time, only a single slave is performing as an active interface. In case of failure of the active interface, the slave interface acts as an active one. This mode provides also fault tolerance.

Flight creates a bond interface on top of LC1 and LC2, which is named as bond0. This results in establishing a seamless VLC connection between each AGV and the corresponding LAP. In this setup, LC1 and LC2 are configured as the primary and slave links, respectively. In order to detect the VLC link failure in VVLC, Flight uses Address Resolution Protocol (ARP) monitoring towards a network gateway near the LAPs, which in this setup, is the switch between the remote server and LAPs. The configured bond interface transmits an ARP request signal every t milliseconds, which is based on the received ARP replies transmitted by the defined target, and makes a decision over which physical interface to transmit the traffic.

## IV. PROBLEM STATEMENT

In VVLC network the need for reducing the network outage duration is high, especially during the handover process. Let us consider mobility of AGV over a given path. A mobile device connects to the first VLC link on entering the first LAP coverage area and continues moving towards the next LAP coverage area. On entering the overlapping region, handover is initiated and a new VLC link is established with the second LAP. In the case of shadowing, where the VLC line of sight (LOS) path experience link failure (permanent or temporarily), handover is also initiated connecting AGV to the first available LAP. Therefore, in order to decrease the network outage during handover, the times required to detect link failure and to establish a new connection must be minimized. In [2], the outage duration during handovers for Flight was reported for uplink and downlink. In this paper, we consider two main interface selection bonding schemes for VLC and evaluate their impact on the handover outage duration due to mobility or shadowing.

## V. CHANNEL SELECTION METHODS DESCRIPTIONS

Using Linux network bonding method, we consider two methods in order to detect the path failure and reselect the active link in the bonding setup. In this approach, we can specify how the active link is selected as a primary interface and in case of its failure how the bond interface switches to the slave link. In the first method, which is based on the default values in network bonding, the defined primary link is always the active link. This is called “always” in this work, which refers to the slave link being active when the primary link is down. Note that, when

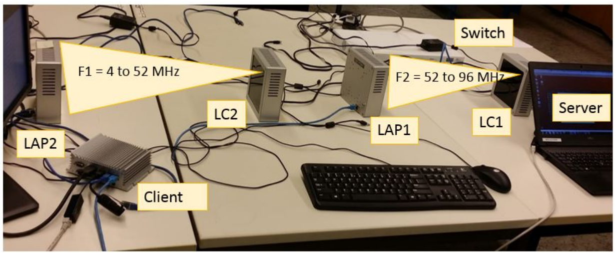



Fig. 2: Flight prototype

the primary link becomes available the bond interface selects it always as a new active link. In the second method, named “failure” in this work, the primary slave becomes the active slave only if the current active slave fails.

There are pros and cons with two methods outlined before. Depending on the VVLC network setup and architecture and the defined ARP interval value, the two methods may or may not improve the throughput. In case of using the “always”, the bond interface has the advantage of monitoring the primary link and making it the active link. Therefore, no need to measure the link’s parameters on a continuous base. In this case, depending on the failure time length of the primary link, one can flip between the predefined primary and slave links. For longer primary failure time the link switching within the VVLC network is reduced. The other significant advantage is no path bouncing that might occur in the network using small ARP interval values. However, the major disadvantage is when the primary link, experiences blocking due to shadowing and, where the link is no longer available for a short period. In this case, the primary reselection procedure takes place twice within a very short time duration, which may result in lost packets. The “failure” method has an advantage of bouncing avoidance between primary and current slave interface and with no planned switching to the primary link once it comes up. This helps to provide a more robust VLC connection. The disadvantage is when the quality of the current salve becomes poor and it will not switch until the current slave is not yet disconnected.

## VI. EXPERIMENTAL RESULTS

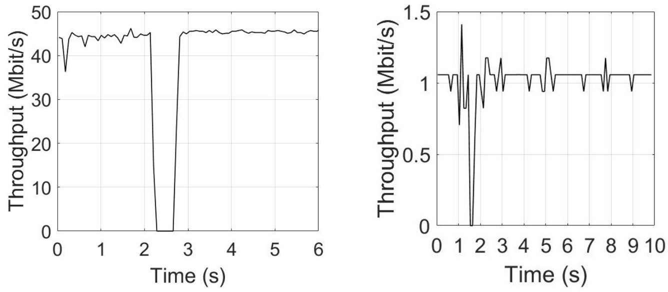
As outlined earlier, in VVLC networks the handover is due to the mobility and shadowing. In this work, we consider both possible link blockage scenarios and using an experimental prototype evaluate the handover duration for the two methods of “always” and “failure”.

It is worth mentioning that, in all experiments we implement

TABLE I: Experimental parameters

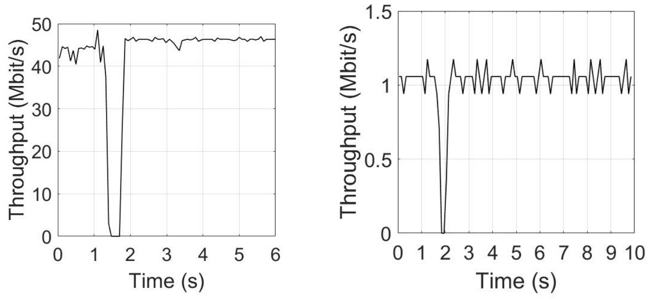
| Parameter | Value |
|---|---|
| ARP interval | 100 ms |
| Pauses between periodic bandwidth | 5 ms |
| ICMP packet size | 100 byte |
| Number of ICMP packet for transmission | 1000 |
| LC1 and LAP1 frequency range | 4-52 MHz |
| LC2 and LAP2 frequency range | 52-96 MHz |
| LC’s field of view | 60 degree |
| Distance between LCs and LAPs | 50 cm |

the Flight architecture as presented in Fig. 2 and consider the ARP monitoring method for detecting the VLC link failure. ARP is chosen since it performs based on communications




(a) TCP (b) UDP

Fig. 3: ”Always” Channel selection method in mobility usecase.




(a) TCP (b) UDP

Fig. 4: ”Failure” Channel selection method in mobility usecase.

to the predefined ARP target and can detect the link failure even if the link is beyond the nearest connected switch. The variable parameters are (i) a method of interface selection while bonding; (ii) mobility and shadowing use case scenarios; and (iii) transmitting three different network traffics as TCP, UDP and internet control message protocol (ICMP). Each experiment is repeated ten times to ensure consistency. Table I presents the key experimental parameters. In addition, Fig. 2 demonstrates the Flight prototype which is composed of a pair of OSRAM VLC units operating at F1 frequency band as a LAP and LC in the VVLC network.

### A. *Channel selection in mobility*

In these experiments, we have used the topology shown in Fig. 1. we emulate a complete link failure due to mobility by a manual link blockage. We consider two selection methods for the primary interface as “failure” and “always” for the bonding configuration.

Experiment 1 - “always”: To evaluate and measure the network throughput for unicast and broadcast transmissions for the uplink (i.e., AGV and the remote server), both TCP and UDP packets are generated and transmitted separately. The average throughput for TCP and UDP are shown in Fig. 3. Note that, the drop in the throughput is due to handover. For TCP it will take 0.67 s to establish a new VLC link with the next available LAP. Whereas for UDP, it will take 0.3 s for the bond interface to switch over the slave backup link and establish a new VLC connection via the next LAP.

Experiment 2 - “failure”: Here, the bonding configuration is setup to use “failure” as the primary interface reselection method. As shown in Fig. 4, both schemes display the same throughput profiles. This is because with AGV moving between different LAPs coverage areas the primary connection is lost and therefore there is no option for the AGV to reconnect to the first primary interface. Note, the handover outage duration stays almost the same when using the “always” channel selection method.

### B. Channel selection in shadow

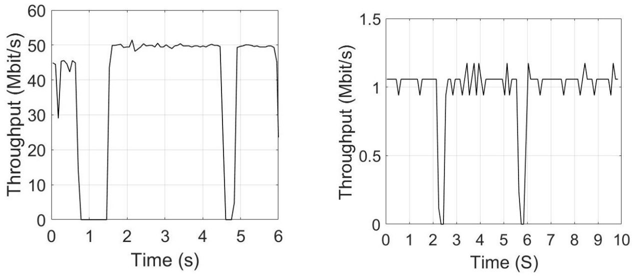
In this subsection, we consider shadowing to evaluate the performance of the two channel selection methods considering the handover. We emulate shadowing by blocking the link temporarily for a couple of seconds.

Experiment 3: Here, we show that, under shadowing imposed link blockage, which last for a very short time, the default channel selection method of “always” does not perform well. This is because, with shadowing the bond interface connectivity via the primary link is lost and the slave link is used as the backup VLC link. However, shadowing may not last long and therefore the primary link will once again become available. Note, the bond interface will need to flip back to the primary interface, which is the default link for the “always” channel selection method. In this case, the VVLC network will experience two link losses with increased handover delay time. Figures 5 show the link throughput during handover under shadowing for TCP and UDP packets transmissions while AGV is connected to the remote server. Note, for TCP the throughput is for the uplink (i.e., AGV to the remote server).AS shown in Fig. 5, there are two notches in the throughput. This is because (i) for TCP the channel selection method was set to “always”, which results in connection loss during the handover. Therefore, we observe an increased value as 1.34 s for the handover outage duration. And (ii) for UDP, the interface selection happening twice due to shadowing and the handover network outage increases up to 0.9 s in total due to the extra channel switching in the VVLC network.

Experiment 4: This investigates the shadowing effects in order to block the VVLC link using the “failure” channel selection method configured on top of the bond interface on AGV. Fig. 6a the TCP traffic is transmitted and shadow caused a handover which occurs after the first second of the measurement. Using a “failure” channel selection method improves the handover network outage in comparison using “always” method. It decreases the TCP handover network outage up to 0.83 s which is almost two times less than when “always” method as a default method was used. Moreover, in Fig. 6b an impact of “failure” primary reselection method has been shown in a shadow use case during UDP traffic transmission. As it is shown the throughput turns to 0 only shadow occurs and the bond interface dose not switch to the primary link right after it becomes available and it leads to the handover network outage improvement to 0.4 s.

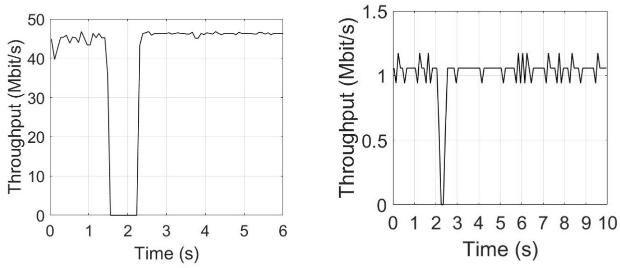
### C. VVLC link quality in both shadow and mobility use cases

In order to monitor and check the VLC link quality during the handover caused by shadow and mobility in the VVLC network environment, we evaluate the link quality via fping tool transmitting ICMP traffic between the remote server and the client machine installed on the AGV for the VLC network monitoring.




(a) TCP (b) UDP

Fig. 5: “Always” Channel selection method in shadow usecase.




(a) TCP (b) UDP

Fig. 6: “Failure” Channel selection method in shadow usecase.

Experiment 5: This experiment uses the fping tool to count the number of packets lost in both use cases of shadowing and mobility during the handover in VVLC environment and use the network parameters defined in Table I. As shown in Table II, the type of interface selection method does not have a significant impact on the mobility use case, however it directly has a critical impact on the shadowing use case scenario. The average number of packets lost during the VLC handover under shadowing using the “always” interface selection method increases to more than 15, however, using a “failure” method it reduces up to 10. In addition, there is a considerable difference in the minimum number of packets lost under mobility and shadowing. In shadowing, using the “failure” and “always” methods the number of packets lost are reduced and increased to 2 and 7, respectively.

TABLE II: Number of the packet lost Vs handover causes.

| **Statistics** | **Shadow** | | **Mobility** | |
|---|---|---|---|---|
| **Number of Packet lost** | ***Always*** | ***Failure*** | ***Always*** | ***Failure*** |
| Average | 15.66 | 9.83 | 2.4 | 2.4 |
| Minimum | 7 | 2 | 1 | 1 |
| Maximum | 18 | 16 | 6 | 5 |

## VII. CONCLUSION

This paper provided analyses results for mobility and shadowing use cases based on the Flight VLC network architecture and studied the impact of two main interface selection methods in network bonding schemes. We showed that, the “failure” interface selection method has a greater impact in decreasing the outage duration during the possible handovers caused by shadowing within the network. Therefore, it is a significant factor to use a "failure" channel selection method in place of default value of the bonding scheme for both scenarios, especially under shadowing.

Future work will include consideration of different interface selection methods, where we can select the best link to transmit and receive the traffic based on different important parameters such as the VLC link's speed and duplex.

## ACKNOWLEDGMENT

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